Comparing modern and classical perspectives on spider silks and webs§

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Abstract

Spiders have always fascinated humankind as whilst they are often reviled, their product, the web and its silk, are commonly viewed in awe. As such, silks' material properties and the fear and fascination surrounding the animals that spin it, are seen to play an important role in the development of many cultures and societies. More recently this is even more so with the formalisation of this inspiration in scientific and technical communities through biomimetics. The aim of this work is to reflect on the beginnings of our relationship with silk and discuss concepts associated with spider silks and webs in ancient Greek and Roman times whilst comparing this with our current understanding of the field. In this way, ancient texts, namely Greek and Latin, are found to intersect with

modern advanced disciplines, ranging from architecture to medicine to physics. This allows us not only to understand how natural observation has evolved from antiquity to today, but also how such a highly interdisciplinary research network has been spun by some shared conceptual threads.

0. Introduction

Humankind has been forever captivated by the marvels of nature, exemplified formally through the formation of research fields such as biomimetics[1]. Even though this term was coined only in the latter half of the 20th Century[2], the process of trying to extrapolate information from nature in order to address human challenges has been present in the societies of every epoque[3]. Naturally driven by our challenges and across the ages, the process of observation, imitation and application has defined part of our cultural and technological heritage, creating both a conceptual space and a framework for development[4]. In this context, spider silks and spiders' spinning behaviours are superb examples, representing permeability throughout our culture and in several areas of technology and society[5].

Spider silks are made of structural proteins that are spun from liquid feedstocks into solid fibres used outside the body[1]. Spiders can produce several different types of silks (up to seven), each one evolved through millennia of natural selection to serve a specific biological role, from eating to mating to flying[6].

In order to perform these functions, spider silks have been under strong selection for outstanding physical properties[7]. Nowadays, the spider silk community has grown globally due to increasing interest in finding technological applications of these materials[8] or overcome current limitations in materials design. Yet despite the exciting and clear focus for the future of silk, what of its past? We propose that by looking back on how our fascination

§ A more ancient-texts-based version of this paper has been submitted to the journal "AKAN - Antike Naturwissenschaft und ihre Rezeption".
1 Vincent *et al*. 2006.
2 *ibid*.
3 Pugno 2019.
4 Holland *et al*. 2019.
5 Morgan 2016, pp. 133–41.
6 Brunetta–Craig 2012, pp. 2–15; Scott *et al.* 2018; Morley–Robert 2018; Greco *et al*. 2019.
7 Eisoldt *et al.* 2011.
8 Vepari–Kaplan 2007; Holland *et al*. 2019.

with spiders and silk has developed we may not only appreciate more where we are going, but also the most expedient way of getting there.

Previous works have sought to provide a review of spiders and their silk in ancient history, however none through the lens of our current understanding of the animal and the material. One example is the German book by B. Rieken, *Arachne and ihre Schwestern. Eine Motivgeschichte der Spinne von den 'Naturvölkermärken' bis zu den 'Urban Legends'* (Münster 2003). Although the author provides the reader with a satisfactory selection of passages (the ones from ancient Greece and Rome are found at pp. 122–26), his aim was to write a 'Kulturgeschichte der Spinne' ('spider's cultural history', as he points at p. 7), and as such he does not focus on the natural nor scientific reliability when presenting ancient material. More focused on zoological knowledge in antiquity, another (still) fundamental work is the monography published by I. Beavis, *Insects and Other Invertebrates in Classical Antiquity* (Exeter, 1988). The author offers a very detailed account of ancient natural observations and knowledge, devoting chapter II.7 to spiders in ancient Greece and Rome (focusing on identification; natural observation; popular attitudes; etc.), the reader however still misses a broader point of view surrounding the evolution of knowledge about spiders and the human uses of spider silk. The aim of the present paper is to fill this gap by providing the reader with a more complete picture.

This work deals with the knowledge of spider silk and web-building in ancient Greece and Rome and compares it with the same underpinning concepts in modern science. Our purpose is not to discuss any and all ancient mentions of spiders; rather, we selected a number or representative passages which suited our diachronic and interdisciplinary approach. In order to give a picture as clear as possible, this paper is divided into four parts. The first deals with natural observation of spiders using their silks and web. The second relates to the material itself and its possible uses. The third concentrates on their spinning and web construction and how they were/are described and taken as a model by men. The final part is related to the cultural influence that spiders and their weaving had/have in human social culture.

1. Natural observation

We define natural observation as the act of observing a specific phenomenon in nature and consequently describing it. In the case of spiders, that

phenomenon could be a particular spinning behaviour, building a web or notes on their biology.

The first question we should ask is: which species did the ancients know? Of the genus of arthropods, only the two orders of spiders (ἀράχνη/*Araneae*) and scorpions (*Scorpiones*) were commonly known in Antiquity. The third order, that of non-venomous barrel spiders (*Solifugae/Solpugida*), a scourge in Arabia and tropical Africa, was apparently found only in Greece (φαλάγγιον/*Phalángia*) and Spain (*Salpugae*, Plin. *NH* 29.92)[9]. The difference of usage between ἀράχνη and φαλάγγιον can be drawn from extant texts, and it is explained by Beavis[10]: "Ἀράχνη may be used as a general word to cover both classes of spiders, but in its more precise sense it comprehends those species which are known as being harmless to man, most particularly those which spins continuous webs. […] Φαλάγγιον, on the other hand, is applied to the much-feared venomous spiders; plus those reputed to be venomous, since popular fear of poisonous creatures expanded this class of arachnids somewhat beyond its legitimate range"[11]. The Romans on the other hand, had only one word, *araneus*, used for spiders in general, however for venomous species they transliterated the Greek name into *phalangium*.

Ancient observation and interest surrounding spiders can be traced back to one of the first literary works, Homer's *Odyssey*, where spider webs are mentioned twice. The first mention entails a metaphor which implies that spiders weave in abandoned places, referring to Odysseus' marital bed, which has been left empty for twenty years due to his travels away from home whilst fighting the Trojan war: *Od*. 16.34–35 "[…] *and the couch of Odysseus, for want of sleepers, perhaps lies full of foul spider webs*"[12])²². The second mention involves a more elaborate image, relating to Greek mythology and the act of adultery between Ares, god of war, and Aphrodite, goddess of love. In this episode they make love illicitly, hidden in the house of Hephaistos, husband of Aphrodite. When Hephaistos finds out what happened, furious of their deceit, he arranges a trap in case they do it again. The trap is inspired by a spider web for its fineness and difficulty to be seen (*Od*. 8.272–81, esp. 279–81 "*and many (bonds), too, were hung from above,*

[9] Hünemörder 2001.
[10] Beavis 1988, p. 34.
[11] For the identification of the *Phalangia* varieties see Beavis 1988, pp. 46–54.
[12] Transl. Murray 1995, p. 121.

from the roofbeams, fine as spiders' webs, so that no one even of the blessed gods could see them, so cunningly they were fashioned"[13]) (Figure 1a,b). In both passages from *Odyssey* the spider's web plays a role in determining the sexual fidelity of a wife[14]. A very close image to *Odyssey* 8.279–81 is also found in the tragedian Aeschylus, which is again related to, and this time architected by, a wife. Here the tragedian describes the king Agamemnon, about to die, wrapped in a spider web designed by his wife Clytemnestra (*Ag*. 1492–93, repeated also al ll. 1516–17, "*Thou hast been brought to lie in this woven spider-web, breathing out thy life by an impious death*"[15])³³. Again, the spider's web is used as a sinister image, denoting cunning rather than skill and used by a weaker figure to capture a stronger one.

From a biological perspective the concept of trap is deeply relevant to a spider's life. In order to get the energy to live, they have to feed themselves and to feed, they hunt. In many species of spiders the use of webs is an incredibly efficient tool to trap prey. Among the variety of traps and hunting skills displayed by spiders, two of them deserve a special mention: the evolutionarily ancient trapdoor (typically belonging to the *Mygalomorphae* suborder) and perhaps the most modern tangleweb of the black widow (*Theridiidae* family). Trapdoor spiders dig a tunnel in the soil at the end of which they build a door with silk threads elongating from it (Figure 1c)[16]. Their purpose is to extend the spiders' territory insofar that, when a prey touches one of the threads, the spider is able to pounce and immediately drag it into the very end of the tunnel, where it can be consumed. On the other hand, the trap displayed by *Theridiidae* spiders is very sophisticated and it can be easily associated with the one in Hephaistos's mythological episode. These spiders spin vertical threads from their cobwebs[17] (Figure 1d). The threads are attached to the substrate below with unstable attachment discs that when touched, detach and lift the prey up, suspending it helplessly until eaten[18].

[13] Transl. Murray 1995, p. 293.
[14] For a metaphorical, gender-based reading of the two Homeric passages see Holmberg 2003.
[15] Transl. Fraenkel 1950, p. 183.
[16] Main 1957.
[17] Hódar–Sanchèz-Pinero 2002.
[18] Nyffeler–Vetter 2018.

Another trap that is accurately described in ancient literature is the one observed by Pliny the Elder, *Natural History* (*NH* 11.28,82) that says:

"*How its bosom bellies to the breezes so as not to reject things that come to it! You might think the threads had been left by a weavy weaver stretching in front at the top; but they are difficult to see, and, like the cords in hunting-nests, when the quarry comes against them throw it into the bosom of the net. With what architectural skill is the vaulting of the actual cave designed! And how much more hairy it is made, to give protection against the cold!*"[19].

This quotation is interesting for two reasons. The first one relates to the accuracy of describing a trap with vertical threads. This could be related to the webs of *Linyphidae* spiders that normally build a 3D structure composed of a canopy surrounded by vertical threads which serve to catch flying prey before throwing it into the canopy[20]. Interestingly, the description of Pliny seems to be very similar and precise to the one of recent biology manuals. In Foelix (2011, p. 155) one reads: "*The very delicate webs of the linyphiids are also horizontal, but convex, sheets with similar vertical threads that serve as tripping lines for insects […] In most cases an insect becomes trapped between the vertical "knock-down" threads. The spider, hanging beneath its sheet, quickly rushes by and shakes the web so that the victim will fall down. The bite is applied through the fine meshwork of the horizontal sheet, and the victim is pulled down*".

The second aspect is even more peculiar. Pliny seems to refer to the fact that silk is a good thermal insulator. This intuition has been confirmed by modern achievements on the properties of spider silk and it is the reason why spiders are able to overcome the cold winter by insulating themselves in a silk cocoon[21]. Recent work has also identified silks to be very efficient thermal conductors, although this appears to still be a controversial area in the literature[22].

However it is not just the properties of silk in the web that has captured the attention of the ancients, but their architecture also, with the best known being the orb web (Figure 2). Excluding literary metaphors or mythological

[19] Transl. Rackham 1940, p. 483.
[20] Foelix 2011, pp. 155–57.
[21] Curniff *et al*. 1994.
[22] Huang *et al*. 2012; Xing *et al*. 2013; Fuente *et al*. 2014.

accounts it was Aristotle who first described in the *History of Animals* spider spinning behaviour and web construction (*HA* 623a 9–17):

"*It weaves by first stretching thread to the extremities in every direction, then it lays down the radii from the middle (it takes the middle with fair accuracy) and on these lays down the woof so to speak, and then weaves them together. Now the bed and storage she arranges elsewhere, but she does her hunting at the centre where she keeps watch. Then when something has fallen in and the centre has been moved, first she binds it round and enwraps it with webs until she has made it helpless, then she lifts it up and carries it away …*"[23].

The first aspect to be noted is the accurate description of the hunting, which resembles modern scientific literature[24]. In particular, many orb-weavers monitor threads vibrations, which could be caused by a potential prey or a mate, at the centre of the webs[25]. Nowadays, we know that the propagation of such vibrations can be tuned, like a musical instrument, by the spiders in order to optimize signal transmission in the web[26]. Moreover, this passage is very interesting for two reasons. The first is the comparison with human weaving, since Aristotle employs the word "woof" which is normally used in ancient Greek to describe human manufacture. We will show in paragraph 3 the relevance of comparing human and animal spinning and how spiders' weft is seen as an example to imitate. Secondly, the parallel to geometry, entailed by the sentence "*it takes the middle with fair accuracy*".

This last comparison is also found in another text, namely *The Characteristics of Animals* by Aelian (*NA* 6.57), who remarks that the spider has no need of Euclid (the most famous ancient scholar of geometry):

"It seems after all that spiders are not only dexterous weavers after the manner of Athena […] *but they are by nature clever at geometry. Thus, they keep to the centre and fix with the outmost precision the circle with its boundary based upon it, and have no need of Euclid, for they sit at the very middle and lie in wait for their prey"*[27].

[23] Transl. Balme 1991, pp. 329–31. A commentary to the passage is in Beavis 1988, pp. 36–7 and 41.
[24] Foelix 2011, pp. 157–80.
[25] Masters–Markl 1981.
[26] Mortimer *et al*. 2014; Mortimer *et al*. 2016.
[27] Transl. Schonfield 1959, pp. 77–79.

This observation, apparently without a context, can be inserted in a broader discourse: the ancients applied also to the spider the dichotomy between τέχνη (*techne*) and φύσις (*physis*), 'art' and 'nature', asking if the spinning ability of spiders was learnt (*techne*) or innate (*physis*). Both Aristotle (in the 4th century BC) and Aelian (in the 2nd century AD) in the two passages above asked themselves this very question and concluded that it was actually an innate characteristic. The hallmarks of this innate sense are that it comes untaught and it is shown by all members of a given species in the same manner: "*the instincts of animals are untaught*", says Hippocrates (*Nutriment* 39.1), and Galen (*On the Usefulness of the Parts* 1.3) adds: "*it seems to me that other animals acquire their skills by instinct* […] *and spiders spinning and weaving. I judge from the fact that they are untaught*"[28]. For a detailed account see also Dickerman 1911, who shows to what extent the ancients admired works of animals, among which spiders were praised for their intelligence.

Nowadays we know that spiders spin webs using genetically encoded information which manifest as a sublime set of in-built rules that can be followed from hatching[29]. However like all of nature, there is flexibility in these rules and spiders are actually able to modify their webs to adapt to their environment and improve their efficiency when necessary[30].

2. The material: spider silk.

The first thing that was noticed in antiquity (and that today is still source of fascination) is the fact that spider silk is strong and spider webs robust. When compared to our own materials, many spider silks are stronger than steel and more deformable[31] allowing spiders to capture and lift objects or prey[32]⁴⁴, even bigger than themselves (Figure 3a). This unique combination of strength and deformability leads to the property of most interest for today's researcher, toughness, the ability to absorb energy before breaking, of which spider silk is unmatched in nature[33].

[28] Transl. May 1968, p. 70.
[29] Reed *et al*. 1970; Pitt *et al*. 1972; Krink–Vollrath 1997.
[30] Foelix 2011, pp. 180–82; Herberstein 2012, pp. 57–85; Boutry and Blamires 2013.
[31] Vollrath–Porter 2006; Cranford *et al.* 2012; Greco *et al.* 2020.
[32] Pugno 2018.
[33] Agnarsson *et al*. 2010.

In this sense, an accurate description of the spider web is found in Pliny's *Natural History* (*NH* 11.28,83–84):

"*Then its strength – when is it broken by the winds? What quantity of dust weighs it down? When the spider is practising its art and learning to weave, the breadth of the web often reaches between two trees and the length of the thread stretches down from the top of the tree and there is a quick return right up the thread from the ground, and the spider goes up and brings down the threads simultaneously. But when a catch falls into the web, how watchfully and alertly it runs to it! Although it may be clinging to the edge of the net, it always runs to the middle, because in that way it entangles the prey by shaking the whole*"[34].

Although our awareness has deep roots, only recently it has been discovered one of the reasons why spider orb webs are so efficient in bearing winds loads. Namely, spiders produce special anchorages on the surfaces made of a specific silk used only for this purpose[35].

Mechanical properties apart, being a natural and a protein-based material, spider silk has interesting biological properties. It is indeed not perceived as a threat by human body cells, an observation scientifically proven this century when the first studies on the cytocompatibility of spider silk were performed[36]. Moreover, it seems that bacteria struggle to proliferate and growth on spider silk's surface due to an absence of available nitrogen[37]. These properties, thus, have become extremely interesting in terms of possible biomedical applications. However, the possibility to use spider silk as a basic material for medical purposes is far from recent[38]. In particular, the medical use of spider silk is documented by various ancient sources. Dioscorides Pedanius, an ancient Greek doctor, botanic and pharmacist who lived in Rome during Nero's age (1st century AD), stated that spider silk can be used to heal the third and the fourth fever. On the other hand, in his work *On Medical Material* he said that, if boiled with other ingredients, spider silk is useful against earache (*MM* 2.63):

[34] Transl. Rackham 1940, p. 483.
[35] Cranford *et al*. 2012; Pugno *et al*. 2013; Greco *et al.* 2020.
[36] Allmeling *et al*. 2006.
[37] Zhang *et al*. 2019.
[38] Holland *et al.* 2019.

"*Spider, the animal, which some call* 'holkos' *or* 'lykos'*, kneaded on a limen pad, plastered onto a linen cloth, and applied to the forehead or the temples, cures fits of tertian fever. When plastered on, its web staunches the blood and maintains the surfaces of sores free of inflammations. There is also another type of spider that spins its web white and dense. It is reported that this web cures fits of quartan fever when packed in a pouch and hung from the arm. And it helps for earaches when boiled with unguent of roses and the liquid is instilled into the ears*"[39].

Moreover, Galen (*On Simple Drugs* vol. 12 p. 343,1 Kühn) documented the use of the silk as uninflammatory to protect shallow wounds. However, the richest account of the uses of spider silk for medical purposes was given by Pliny in *Natural History*, a fundamental work for ancient Romans who started to get in touch with foreign remedies. Pliny indeed did little, if any, independent research, but collected receipts, botanical and animal, from any available source to him at the time[40]⁵⁵. Spiders and their silk are found as treatments for a wider variety of diseases and health conditions: for the breasts after delivery (*NH* 30.131); fractured skull and for bleeding after razor wound (*NH* 29.114); eye fluxes (*NH* 29.131–32); bruised joints (*NH* 30.78); to be put on temples to cure fever (*NH* 30.104) or nose bleeding (*NH* 30.112); for teeth problems (*NH* 30.27) and also for earache (*NH* 30.26). Accounts of use by later authors are given in Beavis (1988, 43–44).

Importantly the potential to use spider silks in medicine has never vanished from our culture. What has changed though is the field of medicine itself and the applications for silk[41]. One example of the chronological persistence of the relationship between spider silk and medicine is given by the study of M. Bon (1710), the first published scientific paper dealing with spider silk in medicine. In that work, together with the description of some methodologies to collect the silk, Bon described how spider silk could be used not only for manufacturing and fabrics, but also as an example to take inspiration from for developing medical technologies.

Nowadays, the focus of spider silk in medical applications has shifted from the past[42] (where mainly fibres and extracts were exploited). Whilst the range of

[39] Transl. Beck 2017, p. 108.
[40] Jones 1963.
[41] Holland *et al.* 2019.
[42] Tahir *et al.* 2017; Holland *et al.* 2019.

applications is not yet as broad or as deep as those exploited by the ubiquitous silk from the mulberry silkworm *Bombyx mori* (Figure 3b) new biomedical applications of spider silks have been discovered and largely pivot around the paradigm-shifting discovery of recent times that silks can be *unspun*. For spider silk, the most common uses to date requires transforming fibres into hydrogels, nanoparticles, films or foams which are used primarily for tissue engineering or drug delivery[43]^{6–12}^{6–12}. However progress in this area requires innovation in up-scaling, as these applications require large amounts of spider silk[44] and this in particular, much like the calls of M. Bon 300 years ago[45], represents one of the main challenges for the field[46].

Hence we have discussed how the material itself is therefore interesting and remarkable in properties, but even more notable is how spiders build webs. The skills in creating synergy and efficiency in structures is a peculiarity of spiders, the only creatures capable of a perfect balance between the quantity and the topology of the materials with the supreme efficiency of the overall structure: the web.

3. Spider weaving as a model

The significance of weaving within ancient societies, especially the Athenian one, has been investigated by several anthropologists, among which J. Scheid and J. Svembro in their book *Le metier du Zeus: Mythe du tissage et tissue dans le monde gréco-romain* (Paris 2003). We shall not repeat their conclusions here, rather we shall focus on the relationships between the spinning of spiders and the weaving of men, and the imagery which the comparison originates.

In archaic Greek literature, the spider's art is mentioned in relation to the weaving of the women in Hesiod, *Works and Days* (776–78). In this passage, we find the spider and its weaving as something that the man should imitate for his craft, thus the spider is seen as an example to mirror.

[43] Huemmerich *et al*. 2006; Humenik *et al*. 2011; Schackt *et al*. 2015; Jastrzebska *et al*. 2018; Gustafsson *et al*. 2018; Dellaquila *et al*. 2019; Yang *et al*. 2020.
[44] Rising–Johansson 2015; Greco *et al.* 2020.
[45] Bon 1710.
[46] Koeppel–Holland 2017; Edlund *et al*. 2018.

"*[…] but the twelfth is much better than the eleventh. It is on that day that the high-flying spider spins its web in the fullness of the day and the canny one [i.e. the ant] gathers together its heap.*"[47].

According to the philosopher Democritus (quoted by Plutarch, *On the Cleverness of Animals* 974a), the spider is, together with other animals, an excellent example of how humans can improve their crafts of weaving and mending. The concept of mending is particularly interesting, for nowadays we know that not all the spiders mend their webs in nature[48]. Hence by observing this natural phenomenon not only helps us to describe the species observed, but it also makes us realise the accuracy of the natural study in these times:

"[…] *animals* […] *of which Democritus affirms that we have been the pupils in the most important matters: of the spider for weaving and mending; of the swallow for house building; of the singing birds, the swan and nightingale, for song, by imitation*"[49].

The mending of spider webs is also found in Aristotle (*HA* 623a) and Pliny (*NH* 9.84). Aristotle (*HA* 623a) and Aelian (*NA* 6.57) infer that the repairs are made at sunrise or sunset, because these are the times when most insects are likely to be caught. As anticipated, there are species of spiders that actually repair their webs by replacing missing threads, typically in their spirals, however some entirely rebuild their webs every day[50]. From an evolutionary perspective in order to be successful, both approaches have been selected to minimise the consumption of energy required by the spider to acquire more food (i.e. the energetic costs of web production and maintenance)[51]. This poses the question where the success in relation to the reconstruction of the web stems from? Some related intuition can already be found in a passage by Plutarch. In the same work where Democritus is cited, Plutarch indeed proposed his own accurate observation (*On the Cleverness of Animals* 966e–67a):

"There is more than one reason for admiring spiders' webs, the common model for both women's looms and fowlers' nets; for there is a fineness of the thread and the evenness of the weaving, which has no disconnected threads and

[47] Transl. Most 2006, pp. 149–51.
[48] Foelix 2011, pp. 157–80.
[49] Transl. Laks–Most 2016, p. 247.
[50] Foelix 2011, pp. 157–80.
[51] Scharff *et al.* 2019.

nothing like a warp, but is wrought with the even continuity of a thin membrane and a tenacity that comes from a viscous substance inconspicuously worked in. Then too, there is the blending of the colours that gives it an airy, misty look, the better to let it go undetected; and most notable of all is the art itself, like a charioteer's or a helmsman's, with which the spinner handles her artifice. When a possible victim is entangled, she perceives it, and uses her wits, like a skilled handler of nets, to close the trap suddenly and make it tight. Since this is daily under our eyes and observation, my account is confirmed. Otherwise it would seem a mere fiction […]"[52].

Plutarch clearly identified that webs are composed not only of one single material, but of different types of silk. Because of this, certain orb webs minimize their damage after an impact with a flying object[53]. Being minimized, the damage does not affect the overall robustness of the structure and as such does not need to be repaired or rebuilt, as it still capable of stopping flying prey[54]. In fact, to achieve this the different silks have a huge mechanical synergy[55] (Figure 4).

Moreover, these quotations show how ancient Greek authors considered the spider and spinning as something that humankind can eventually replicate in its weaving and fishing activities. In other words, the spider is seen as a model for learning from nature. As for the fishing, the uses of spider silks as tools in fishing activities are not confined to the aforementioned quotation. A paper by A. Gell in 1988 shows that spider silks were used by populations of the Solomon Islands as a bait for fishing activities, even if there is no clear evidence on what specific role spider silk covered[56].

It is therefore clear how spider silks spinning and web building can be inspiring for human purposes. Although this influence has been crucial in developing and designing smart technologies and techniques[57], it plays a huge role in affecting deeply our cultural heritage.

[52] Transl. Cherniss–Helmbold 1957, p. 365.
[53] Cranford *et al.* 2012.
[54] Meyer *et al*. 2014; Akasura–Miller 2014, pp. 240–47.
[55] Greco *et al.* 2019.
[56] Barton–Dietrich 2009, pp. 195–213.
[57] Asakura–Miller 2014, pp. 240–47; Basu 2015, pp. 233–37; Miniaci *et al.* 2016; Salehi *et al.* 2020; Guo *et al.* 2020; Pan *et al*. 2020.

4. Continuity in affecting the culture

Spiders, spider silks and webs have a huge effect on our feelings and behaviour. This is scientifically demonstrated by the fact that arachnophobia, the fear of spiders, is recognized as a mental disorder with medical treatments being available[58]. This mental state has deep origins and as we shall explore, is embedded in our cultural heritage.

The best-known (and most continuative from a chronological point of view) artistic expression that sees as a main character a spider is the myth of Arachne. Whilst being a Greek myth, the first detailed expression can be found in Latin literature: Ovid's *Metamorphoses*, Book 6[59]. Arachne was a shepherd's daughter who started weaving when very young. She quickly acquired great ability in weaving that led her to boast herself as a better weaver than Athena and refused to acknowledge that this was only because of the goddess that she had talent in the first place. This offended Athena who challenged the young girl to weave a more beautiful yarn than her own. Athena's work represented four different competitions between mortals and gods with gods punishing the mortals because they dared to put themselves at their level. Arachne's work, on the other hand, represented scenes where gods fooled and abused mortals. When Athena realised that not only the work of Arachne insulted the gods but also that her work was superior, in a fit of rage she destroyed the work of the young girl and hit her on the temple for three times. Arachne, moved by desperation, took a noose and was ready to hang herself when Athena stopped her (Ov. *Met.* 6.134–45):

"The wretched girl could not endure it, and put a noose about her bold neck. As she hung, Pallas lifted her in pity, and said: "Live on, indeed, wicked girl, but hang thou still; and let this same doom of punishment (that thou mayst fear for future times as well) be declared upon thy race, even to remote posterity." So saying, as she turned to go she sprinkled her with the juice of Hecate's herb; and forthwith her hair, touched by the poison, fell off, and with it both nose and ears; and the head shrank up; her whole body also was small; the slender fingers clung to her side as legs; the rest was belly. Still from this she ever spins a thread; and now, as a spider, she exercises her old-time weaver-art."[60].

[58] St-Jacques–Renaud 2006; Granado *et al*. 2007; Bouchart *et al*. 2014.
[59] For a detailed account of the narration see *e.g.* Johnson 2008, pp. 74–95.
[60] Transl. Miller 1977, pp. 297–99.

If, as we have seen in the previous paragraphs, in other literary works humans have learnt the art of weaving from spiders' observation, Arachne's myth inverts this correlation: from a human skilled at weaving comes the most expert animal in this craft, the spider. However picturesque and fascinating, Arachne's myth is not the history of an award but, on the opposite, that of a punishment, by being transformed into a spider. As Rieken (1995) stresses in an article about spiders as symbols in popular tradition and literature, Arachne's myth deals with the question of ability and power, because the Lydian weaver not only wants to be better than any other person, but also better than the gods, which sparks the anger of Athena. As Ovid remarks, "*non illa loco neque origine gentis clara, sed arte fuit*" ("The one was not famous by origin or descent, but by art"): Arachne comes from a humble background and has clear aspirations, but she exaggerates in her will to outdo the gods. On the other hand, Athena's behaviour is also characterized by the interdependence between feelings of inferiority and striving for power. One may object that it is part of the logic of the divine to punish arrogance, but in this myth it gets more personal: Athena is outraged by a mortal and instead of showing superiority, appropriate to a god's behaviour, she shows human weaknesses by becoming angry and makes harmless that what threatens her.

From a cultural perspective the prevalence and popularity of this myth has most likely influenced our attitude towards the spider as it is likely to be closely linked to the fear of threats due to the power assigned to it. One can easily say that Arachne's myth started a chain of imagery and implications which depict spiders as negative and source of fear in several different cultures but also an unobtainable fascination with their artistry. As Kulessa (1991) notices in the preface of her book about spiders, there is no book outside strictly zoological literature "that does not deal with the feelings of fear and disgust that [...] the eight-legged animal triggers in humans in the preface or introduction" („[Buch] das sich im Vorwort oder der Einleitung [...] nicht mit den Angst- und Ekelgefühlen beschäftigt, die das achtbeinige [...] Tier bei den Menschen auslöst"). Nevertheless, as Iles Johnston (2009, 6–7) shows, the affordance related to a subject, the spider for instance, allows the possibility that both positive and negative meanings and feelings can be evoked within a single cultural production. For example, the act of weaving webs discussed above is sometimes understood to indicate industriousness (as in Hesiod *Op.* 777, Aristotle *HA* 622b 23, Aelianus *NA* 1.21, all quoted above), but at the same time

it could signify neglect, carelessness (a place abandoned by humans, as Odysseus' marital bed covered in webs after his long absence, quoted above. More examples can be found in Beavis 1988, 40). The web is sometimes seen as a fine work, produced by intelligent creatures (as in Aristotle *HA* 623a quoted above) and sometimes just a symmetrical product of instinct rather than art (as in Hippocrates *Nutriment* 39.1 and Galen *On the Usefulness of the Parts* 1.3 quoted above).

Apart from the psychological implications of Arachne's myth across times, her story has forever permeated western culture and stimulated and inspired several artistic expressions. To mention a representative one, Gustave Dorè depicted Arachne's transformation in an intense painting inspired by Dante's *Purgatory* 12 (Figure 5a). The painting portraits the peculiar position of an arachnid overturned behind and the metamorphosis is represented there at an advanced stage since all that remains of the human is the face. The intensity of the painting is such that the Italian writer Primo Levi (1985) recognised in it the origin of his arachnophobia.

Other pictorial representations are collected and explained in the survey by Ballestra-Puech *De la toile tissée a la toile peinte* (2006). However the artistic means of expression is not limited to pure painting. In architecture, the imagery of the spider web can be exploited in several ways. Victor Hugo (1837) personified Paris comparing it to a "araignée à la immense toile"[61], referring to the perfection and symmetry of the city¹³¹³. Moreover, the Tour Eiffel has been described in 1889 by the brothers Edmond and Jules de Goncourt as having a "architecture arachnéenne". In more recent times, the Italian architect Mario Botta in collaboration with the engineer Giulio Andreolli realized the MART (Museum of Modern and Contemporary Art of Trento and Rovereto) ceiling (Figure 5b). Although there is no straightforward interpretation, it seems clear that the shape of such structure resembles the one of an orb web (Figure 3), perhaps as symbol of solidity. Another example of the influence of spider webs in architecture can be found in the pavillon designed by the University of Stuttgart[62], inspired by the aquatic spider *Argyroneta aquatica*. This peculiar spider lives almost its entire life under water, where it builds the web with a shape of a bell[63]. This structure is

[61] Gély 1985, p. 821.
[62] Knippers *et al.* 2016, pp. 61–63.
[63] Mammola *et al*. 2016.

filled with air by the spider and it allows the animal to live inside without the need to venture outside several days[64]. Recently, this has been demonstrated to be possible because of the peculiarity of this structure, which acts as a physical gill[65]. Finally, the remarkable work of Tomás Saraceno should be mentioned. This artist emphasizes the connecting, aerial and floating character of the webs to conceptualize the design of floating architectures or the interconnections within the cosmos[66].

There is no space here to investigate the numerous literary expressions of spider's imagery and the re-uses and re-interpretations of Arachne's myth up to the modern days, for which it shall suffice to remember the works by Ballestra-Puech (2006) and Reinhardt (2014, this last one limited to Arachne).

5. Conclusion

Dealing with spider silks and webs means dealing with a part of our own culture. In this work, we have shown a comparison of the concepts related to spider silks and webs between ancient (Greek and Roman as an example of a cultural heritage) and modern societies. We have presented some examples of natural observations performed by ancient people that resemble the modern ones, highlighting the innovativeness of the ancient thought. Then we have shown to what extent spider silks were perceived as a peculiar material with huge potential uses for humankind. The act of weaving itself was seen in the past as a source of inspiration, as much as nowadays. Finally, we have shown the continuity in of spider silks and webs in affecting our culture from many different points of view.

The past is tremendously different with respect to the present. Some ways of thinking and seeing things have been totally changed during the evolution of our society. But we can still find common features that highlight the modernity and novelty of some ancient thinkers that established the basis of our culture. In order to proceed in developing technologies and prosper in our scientific future, we must keep strongly in mind the history of our culture and how has it evolved. We hope that this work gives the basic knowledge to start

[64] Neumann–Woermann 2013.
[65] Seymour–Hetz 2011.
[66] Horn *et al.* 2018.

comparative and interdisciplinary studies between ancient and modern science and culture[67].

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[68] In some references the indication of the pages is missing. This is due to the fact that some scientific journals are available only online and they identify the papers with the number of the issue or a code (here inserted instead the indication of the pages).

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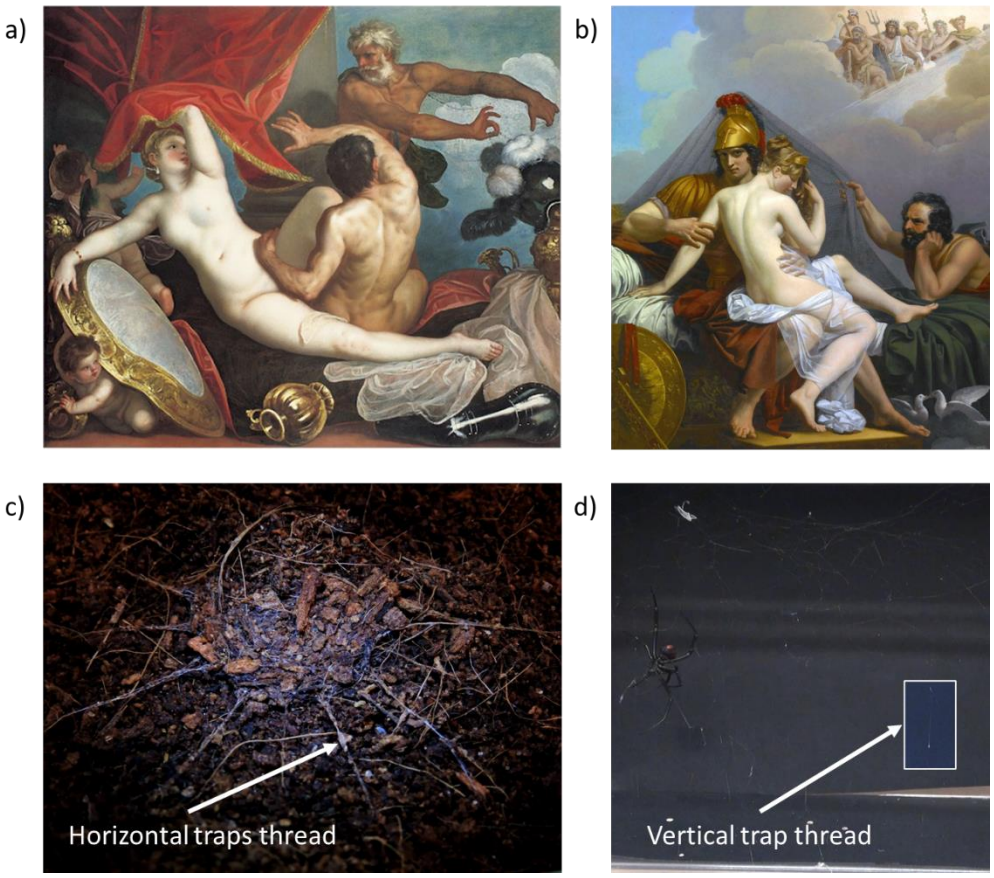

Figure 1: a) Painting: "Marte e Venere sorpresi da Vulcano" (Alessandro Varotari,1640-45). b) Painting: "Marte e Venere sorpresi da vulcano" (Alexandre Charles Guillemot, 1827). c) The entrance of the den of a trapdoor spider with the silk threads that line outside "the door". Courtesy of Aracnofilia (Italian Association of Arachnology, picture by Piergiorgio Di Pompeo). d) Structure of the cobweb produced by Latrodectus tredecimguttatus. The vertical threads are traps that are used to lift the prey, usually ants, and thus make it uncapable of escape by gripping on the surface below.

Figure 2: Orb web produced by a Larinioides sp.. Also after heavy rains, orb webs remain efficient and capable of stopping flying prey, sometimes with even an improvement (Greco et al. 2019). Courtesy of Carmen Buffa.

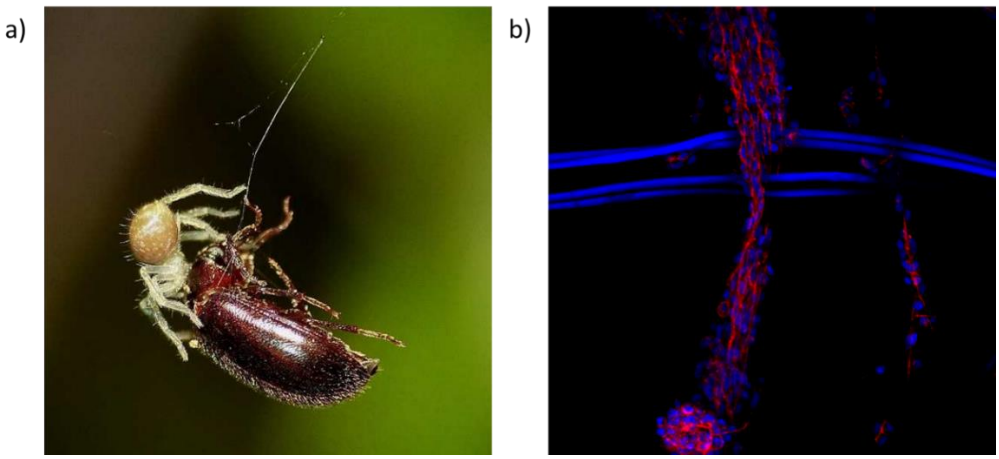

Figure 3: a) Olios argelasius spider that uses a silk thread to lift a prey. Courtesy of Aracnofilia (Italian Association of Arachnology, picture by Luigi Lenzini). b) The silk of Linothele megatheloides spider seems to be better accepted by cells, which adhere and proliferate on it more than in more common silkworm silk fibres. Adapted from (Yang et al. 2020)

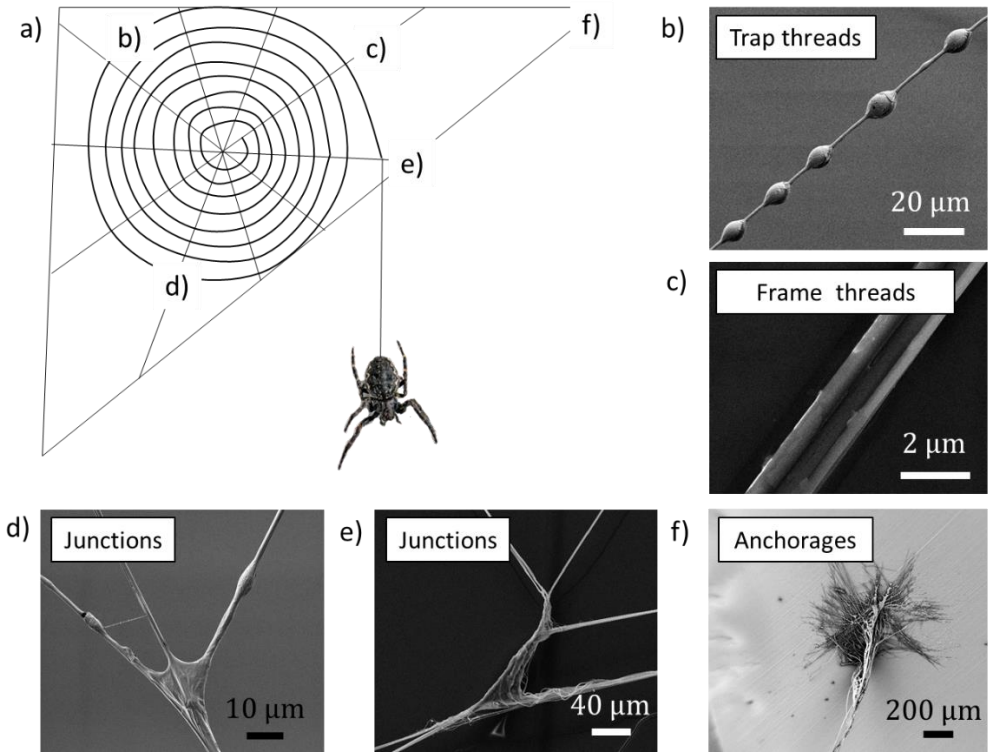

Figure 4: a) Nuctenea umbratica is an orb weaver that produces orb web made by frame threads (c), which are different with respect to the threads used to trap the prey. The web is secured to surfaces by means of anchorages that are produced with the same silk used to join threads along the edges (e). The junctions inside the spiral, on the other hand, are produced by means of a glue (d) that is the same used to produce the glue droplets in the trap threads (b). Adapted from Greco et al. 2019.

a) b)

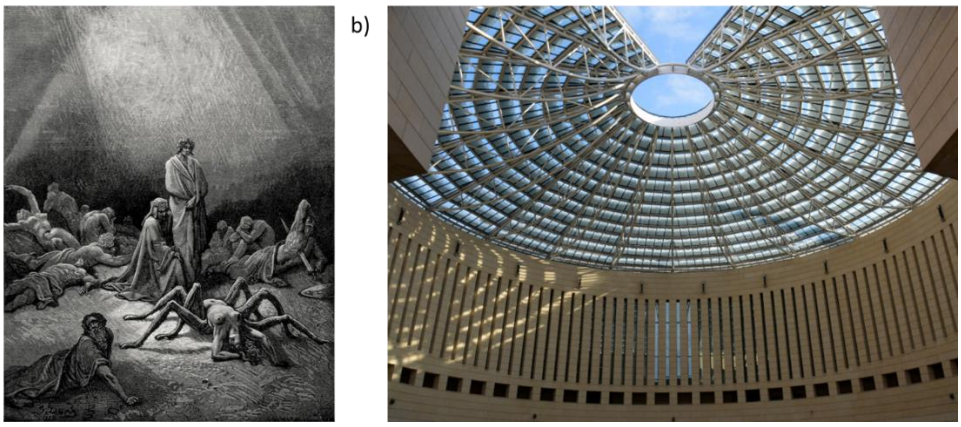

Figure 5: a) Gustave Doré "Arachné au purgatoire" (Paris, Hachette, 1868). b) (photo: www.visitrovereto.it)